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### (54) Breathing apparatus

(57) A breathing apparatus for supplying a supportive inspiration pulse in response to a sensed inhalation effort of a living being connected to the apparatus is described. The supportive response (26, 28, 30) is controlled so that the amplitude of the inspiration pulse displays an inverse relationship to the magnitude of the sensed inhalation effort.

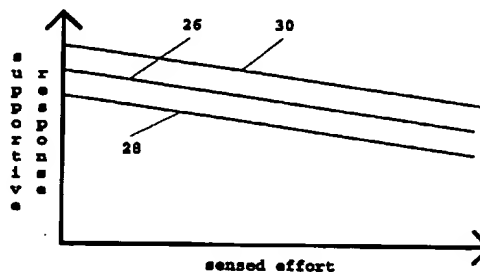


FIG. 2

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## Description

The present invention relates to a breathing apparatus for supplying a respiratory gas to a living being, comprising a delivery unit for supplying inspiration pulses of respiratory gas to the living being, a sensory unit for sensing spontaneous inhalation efforts of the living being and a control unit for controlling the delivery unit so it generates a supportive inspiration pulse in response to the sensed inhalation effort.

Normally a breathing apparatus can operate in a number of different ventilation modes, such as volume control, pressure control, volume support, pressure support, etc. These ventilation modes normally allow a patient connected to the apparatus to trigger an inspiration and/or expiration. These possibilities are for example described in the Operating Manual to Servo Ventilator 300, pages 78-93, AG 0593 3.5, Sweden, 1993.

In an article entitled "Proportional assist ventilation, a new approach to ventilatory support", Younes, American Review Respiratory Disease; 145(1):114-120, Jan. 1992 a specific variation of the pressure support mode is described. In the described mode, Proportional Assist Ventilation (PAV), the apparatus is controlled so that the pressure delivered at the airway increases in proportion to the patient's instantaneous effort. In other words, the patient's own effort to inhale is amplified. The purpose of the PAV mode is to increase comfort for patient, reduce peak airway pressure and preserve and enhance the patient's own reflex.

However, there are some negative effects with the PAV mode as well. One important disadvantage is that this mode may make the patient more dependant on the apparatus in the support mode. Other drawbacks (mentioned in the article) are dependence on spontaneous effort, pressure "run-away" and problem with PAV and breathing patterns.

One object of the present invention is to achieve an improved ventilation mode.

The object is achieved by the invention in that the control unit controls the delivery unit so it generates a supportive inspiration pulse of respiratory gas, the amplitude of which displays an inverse relationship to the magnitude of the sensed inhalation effort, sensed by the sensory unit.

By having an inverse relationship, which may be linear or non-linear, the supportive response from the apparatus will decrease as the patient's own effort increases. In practice this will provide a patient who has low inspiratory drive to receive a sufficient ventilatory assist and as the patient's inspiratory drive increases the support response will decrease so that the patient is induced to activate the respiratory muscles even further.

Improvements of the invention are described in the dependant claims.

In the following, the invention will be described in more detail referring to the figures, in which

FIG. 1 shows an embodiment of a breathing apparatus according to the invention,

FIG. 2 shows a first relationship between inhalation effort and supportive response, and

FIG. 3 shows a second relationship between inhalation effort and supportive response.

A breathing apparatus 2 according to the invention is shown in FIG. 1. The breathing apparatus 2 is connected to a patient 4 for supplying respiratory gas during inspiration and remove expired gas during expiration. The breathing apparatus 2 comprises a ventilator 6 which can receive the gas components of the respiratory gas via gas inlets 8A, 8B and 8C. The gases could for example be compressed air and oxygen. Other gas mixtures are also feasible.

The respiratory gas is delivered to the patient 4 via an inspiration line 10. Exhaled gas is removed from the patient 4 via an expiration line 12, back to the ventilator 6. The exhaled gas is then removed from the ventilator 6 via an exhaust 14 to ambient air or to an evacuation system (not shown). The generation of inspiration pulses is controlled by a delivery unit 16 in the ventilator 6. In response to a control signal from a control unit 18 the delivery unit 16 will generate an inspiration pulse having a defined pressure and/or flow amplitude. The duration of the inspiration pulse may also be controlled by the control unit 18, but it may also be controlled by sensing exhalation efforts from the patient 4.

In order to give a supportive inspiration pulse in response to an inhalation effort from the patient 4, a flow sensor 20 is arranged near the patient 4 in order to sense the patient's 4 inhalation effort. The flow signal from the flow sensor 20 is sent to a sensory unit 22 for determining the magnitude of the inhalation effort. This information is then transferred to the control unit 18 which determines the supportive response to be given in relation to the sensed inhalation effort, whereupon the delivery unit 16 generates the supportive inspiration pulse and delivers it to the patient 4 via the inspiration line 10.

In order to avoid too strong fluctuations in the supportive response, a floating average for the inspiration effort during two or more breaths could be used, instead of the instantaneous inspiration effort in each breath.

In FIG. 2 the relationship between the sensed effort and the supportive response is shown in a diagram, where the line 26 indicates that the relationship is inverse. The supportive response axis indicates the amplitude of the inspiration pulse, i.e. pressure amplitude in pressure control and pressure support modes, flow amplitude in volume control mode, etc. This means that a low inhalation effort from the patient 4 will result in a relatively higher supportive response from the ventilator than for a high inhalation effort. The higher support for low efforts makes sure that the patient 4 will receive a sufficient amount of respiratory gas. As the condition of the patient 4 improves and a stronger inhalation effort is made the supportive response is decreased. This

decrease will cause some extra resistance for the patient 4, thereby forcing the patient 4 to use the respiratory muscles more actively. This respiration training can shorten the recovery time for the patient.

A refinement of this behaviour is also achieved with the breathing apparatus 2 (FIG. 1), in that a pressure gauge 24 is arranged to sense the pressure in or near the patient's 4 mouth. The measured pressure is fed to the control unit 18 which determines the pressure in the patient's 4 mouth at a predetermined time after onset of an inspiration, preferably at 0.1 seconds after onset of inspiration. This pressure, usually designated  $P_{0,1}$  gives an indication of the patient's 4 use of his respiratory muscles. It is also an indicator of the condition of the lungs. If the pressure  $P_{0,1}$  increases during a series of inhalations, the lungs may be stiff and the supportive response is thereby decreased, as shown with line 28 in FIG. 2. For a specific sensed effort the supportive response will thus be lessened. This is made in order to avoid too high pressures within the lung, which may damage the lung. On the other hand, if the pressure  $P_{0,1}$  decreases over a number of inspiration pulses, the supportive response to a specific effort may be increased as shown by the line 30.

In FIG. 2 the inverse relationship was shown as a linear function, but, as can be seen in FIG. 3, the relationship need not be linear. In FIG. 3 the non-linear lines 32, 34 and 36 correspond in function to the linear lines 26, 28 and 30 respectively in FIG. 2.

Several variations of the above described apparatus can easily be realized by the skilled person. For instance, the flow sensor 20 could be replaced by a pressure sensor (or by the pressure gauge 24) for determining the sensed inhalation effort. Also, the inhalation effort can be sensed by sensors within the ventilator and also the pressure in or near the patient's mouth can be determined by measuring the pressure within the ventilator and calculate the pressure in the patient's mouth.

The inverse proportional assist ventilation here described may be used for all ventilation modes and in particular for the pressure support mode. A continuous basic flow of respiratory gas can be delivered by the ventilator 6 and the supportive inspiration pulses would then be superimposed on this basic flow. Such a continuous basic flow provides an immediate supply of respiratory gas at the onset of every inhalation. This reduces the resistance which the patient needs to overcome in order to receive the respiratory gas. Without the basic flow, the apparatus would have to react instantly at the first sign of inhalation, in order to provide the respiratory gas without delay for the patient. As in other ventilator modes, a security arrangement could be included, in which controlled respiration is provided if the patient cannot obtain a sufficient spontaneous respiration within a specific time.

It is also possible to automatically adjust the support so that the control unit selects the best operation mode for the patient, i. e. control or support mode.

Other parameters, such as relation between inspiration and expiration times (I:E ratio) and respiratory rate (RR) may also be varied automatically based on the inhalation effort.

## Claims

1. Breathing apparatus (2) for supplying a respiratory gas to a living being (4), comprising a delivery unit (16) for supplying inspiration pulses of respiratory gas to the living being (4), a sensory unit (20, 22) for sensing spontaneous inhalation efforts of the living being (4) and a control unit (18) for controlling the delivery unit (16) so it generates a supportive inspiration pulse in response to the sensed inhalation effort, **characterized in** that the control unit (18) controls the delivery unit (16) so it generates a supportive inspiration pulse of respiratory gas, the amplitude of which displays an inverse relationship to the magnitude of the sensed inhalation effort, sensed by the sensory unit (20, 22).
2. Breathing apparatus according to claim 1, **characterized in** that the delivery unit (16) supplies a continuous flow of respiratory gas, on which the supportive inspiration pulses are superimposed.
3. Breathing apparatus according to claim 1 or 2, **characterized in** that the sensory unit (20, 22) comprises a flow sensor (20).
4. Breathing apparatus according to any of the above claims, **characterized in** that the sensory unit (20, 22) comprises a pressure sensor.
5. Breathing apparatus according to claim 3 or 4, **characterized in** that the control unit (18) determines a floating average for the magnitude of the inhalation effort for two or more breaths and controls the delivery unit's (16) generation of the supportive inspiration pulse based on the determined floating average.
6. Breathing apparatus according to any of the above claims, **characterized in** that the inspiration pulse is a pressure pulse of respiratory gas.
7. Breathing apparatus according to any of the above claims, **characterized in** that a pressure gauge (24) is arranged to measure the pressure of respiratory gas near or within the living being (4) and that the control unit (18) determines the pressure at a predetermined time after onset of each sensed inhalation effort and controls the delivery unit's (16) generation of the supportive inspiration pulse in dependency on both the magnitude of the sensed inhalation effort and the measured pressure.
8. Breathing apparatus according to claim 7, **characterized in** that the pressure gauge (24) is arranged to sense the pressure in or near the patient's mouth.

terized in that the control unit (18) determines whether the measured pressure changes at each sensed inhalation effort and adapts the inverse relationship based on such changes.

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9. Breathing apparatus according to claim 7 or 8, characterized in that the control unit (18) determines the pressure at approximately 0.1 seconds after onset of each sensed inhalation effort.

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10. Breathing apparatus according to any of the above claims, characterized in that the inverse relationship displays a linear function.

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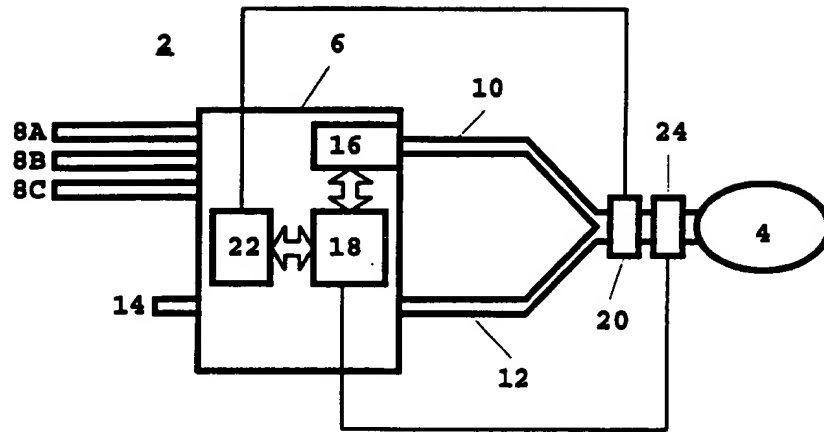


FIG. 1

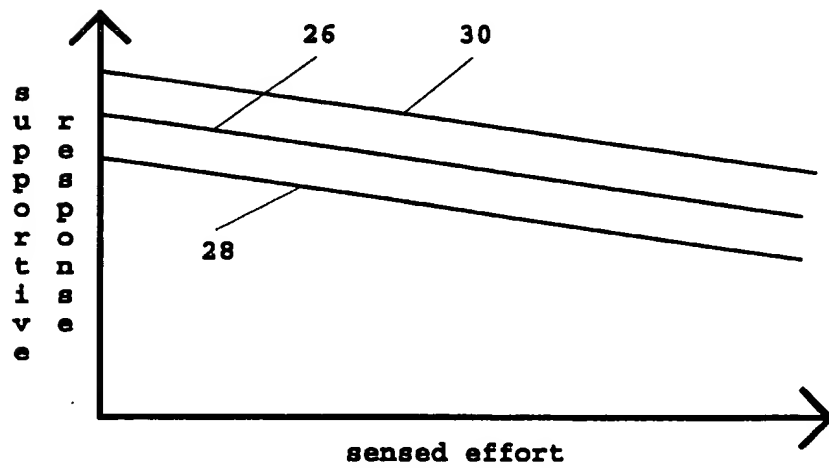


FIG. 2

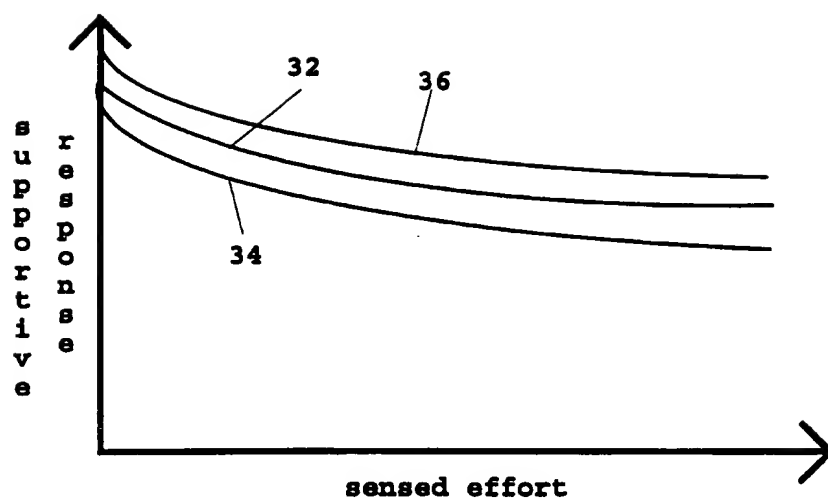


FIG. 3



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# EUROPEAN SEARCH REPORT

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| DOCUMENTS CONSIDERED TO BE RELEVANT   |   |                                  |   |
|---|---|----------------------------------|---|
| Category  | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim                | CLASSIFICATION OF THE APPLICATION (Int. Cl.6) |
| A   | EP, A2, 0459647 (PURITAN-BENNETT CORPORATION), 4 December 1991 (04.12.91)     | 1-10                             | A61M 16/00                                    |
|   | --  |                                  |   |
| A   | US, A, 4421113 (ANDRAS GEDEON ET AL), 20 December 1983 (20.12.83)             | 1-10                             |   |
|   | -----   |                                  |   |
|   |   |                                  | TECHNICAL FIELDS SEARCHED (Int. Cl.6)         |
|   |   |                                  | A61M  |
| The present search report has been drawn up for all claims  |   |                                  |   |
| Place of search   |   | Date of completion of the search | Examiner                                      |
| STOCKHOLM   |   | 26 February 1997                 | EVA JOHANSSON                                 |
| <p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone<br/> Y : particularly relevant if combined with another document of the same category<br/> A : technological background<br/> O : non-written disclosure<br/> P : intermediate document</p> <p>T : theory or principle underlying the invention<br/> E : earlier patent document, but published on, or after the filing date<br/> D : document cited in the application<br/> L : document cited for other reasons<br/> .....<br/> &amp; : member of the same patent family, corresponding document</p> |   |                                  |   |

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